

Upsilon Production In pp Collisions For Forward Rapidities At LHC

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Abstract

This is a continuation of recent studies of $\Upsilon(nS)$ production at the LHC in pp collisions. Our previous studies were for rapidity $y=-1$ to 1 for the CMS detector, while the present study is for $y=2.5$ to 4.0 at the LHC.

Keywords : Quark-Gluon Plasma; upsilion production; forward rapidity; standard model; mixed hybrid theory.

1 Introduction

One of the most important experiments for the understanding of the evolution of our universe is the creation of the Quark-Gluon Plasma (QGP), which is believed to be the nature of the universe when the temperature was higher than about 150 MeV. As the temperature became lower present cosmological theory predicts the QCD phase transition resulted in our present universe of hadrons, at a time about 10^{-4} seconds after the big bang. This is being studied in relativistic heavy-ion collisions at the Relativistic Heavy Ion Collider(RHIC), BNL, USA and at the Large Hadron Collider(LHC), CERN, Geneva. An essential question is the experimental evidence for the creation of the QGP in such ultra-relativistic heavy-ion collisions.

1.1 Mixed heavy quark hybrid and pp collisions

One possible signal of QGP is the production of heavy quark states in relativistic heavy-ion collisions. Studies of heavy quark state production in proton-proton (pp) collisions as a preliminary to relativistic heavy-ion collisions have been carried out [1, 2, 3, 4]. An important observation concerning the nature of heavy quark charmonium and bottomonium states are anomalies: a much larger production of $\Psi'(2S)$ in high energy collisions than standard model predictions [5], and the anomalous production of sigmas in the decay of $\Upsilon(3S)$ to $\Upsilon(1S)$ [6]. The solution of these anomalies was found in the mixed hybrid theory [7]. The $\Psi'(2S)$ state was found to be

$$|\Psi'(2S)\rangle = -0.7|c\bar{c}(2S)\rangle + \sqrt{1-0.5}|c\bar{c}g(2S)\rangle, \quad (1)$$

where c is a charm quark, and the $\Upsilon(3S)$ state was found to have the form

$$|\Upsilon(3S) \rangle = -0.7|b\bar{b}(3S) \rangle + \sqrt{1-0.5}|b\bar{b}g(3S) \rangle, \quad (2)$$

where b is a bottom quark. That is these states have approximately a 50% probability of being a standard quark-antiquark, $|q\bar{q} \rangle$, meson, and a 50% probability of a hybrid, with the $|q\bar{q} \rangle$ a color octet and an active gluon. With a valence gluon it would be natural for these hybrid states to be produced during the creation of a dense QGP.

Using this mixed hybrid theory, it was shown in our recent work [8], upon which the present work is based, that the ratios of $\Psi'(2S)/(J/\Psi)$ and $\Upsilon(3S)/\Upsilon(1S)$ agreed with experimental results, while the standard model for the $\Psi'(2S)$ and $\Upsilon(3S)$ did not.

1.2 Heavy quarkonium state production at forward rapidities

At the LHC the parton distribution functions of the nucleon can be studied in pp collisions, and in pA and AA collisions their modifications in the nucleus for very low values of momentum fraction (Bjorken x). The capabilities to measure charm and beauty particles in the forward rapidity region ($|y| \simeq 4$) using the Muon Spectrometer [9] gives access to the regime of $x \sim 10^{-6}$ in A Large Ion Collider Experiment(ALICE) [10].

Using the Muon Spectrometer [9] in ALICE detector at the LHC, charm and beauty particles can be measured in the forward rapidity region via its di-muon decay. The main goal of the ALICE Muon Spectrometer physics program [5] is based on the measurement of heavy-flavor production in forward rapidity region ($2.5 < y < 4$) for pp, pA and AA collisions at LHC energies. For the relativistic heavy-ion collisions the dependence with the collision centrality and the reaction plane can be studied. In terms of AA collisions, the Υ states are expected to dissociate at a higher temperature [11] than the other quarkonium states, thus proving to be a more effective thermometer of the system. With the $\Psi'(2S)$ and $\Upsilon(3S)$ states having active gluons, measurement of their production can be a test of the creation of QGP.

2 Differential rapidity distribution for $\Upsilon(nS)$ production

In our recent work on $\Upsilon(nS)$ production via proton-proton (pp) collisions we followed the formalism of Refs[2, 3, 4] for $E=\text{energy}=\sqrt{s} = 2.76 \text{ TeV}$ [8] and 7.0 TeV [12], with the rapidity variable $y = -1$ to $+1$, for the Compact Muon Solenoid(CMS) detector. In the present work we calculate $\Upsilon(nS)$ production for the acceptance($y=2.5$ to 4.0) of the Muon Spectrometer in the ALICE experiment [9, 10] at LHC. The differential rapidity distribution for $\lambda = 0$ (dominant for $\Upsilon(nS)$ production) is given by [8] ($A_T = 2.13 \cdot 10^{-5} \text{ nb}$)

$$\frac{d\sigma_{pp \rightarrow \Phi(\lambda=0)}}{dy} = A_T \frac{1}{x(y)} f_g(x(y), 2m) f_g(a/x(y), 2m) \frac{dx}{dy}, \quad (3)$$

$$\begin{aligned} x(y) &= 0.5 \left[\frac{m}{E} (\exp y - \exp(-y)) + \sqrt{\left(\frac{m}{E} (\exp y - \exp(-y))\right)^2 + 4a} \right] \\ \frac{dx(y)}{dy} &= \frac{m}{E} (\exp y + \exp(-y)) \left[1 + \frac{\frac{m}{E} (\exp y + \exp(-y))}{\sqrt{\left(\frac{m}{E} (\exp y - \exp(-y))\right)^2 + 4a}} \right], \end{aligned} \quad (4)$$

with $a = 4m^2/s$, $m = 5$. GeV, and f_g the gluonic distribution function.

Using Eqs(3,4) and parameters given in Ref [8] we obtain the results for $\Upsilon(1S)$ production shown in Fig. 1 at 2.76 TeV and in Fig. 2 at 7.0 TeV in pp collisions for $2.5 \leq y \leq 4.0$.

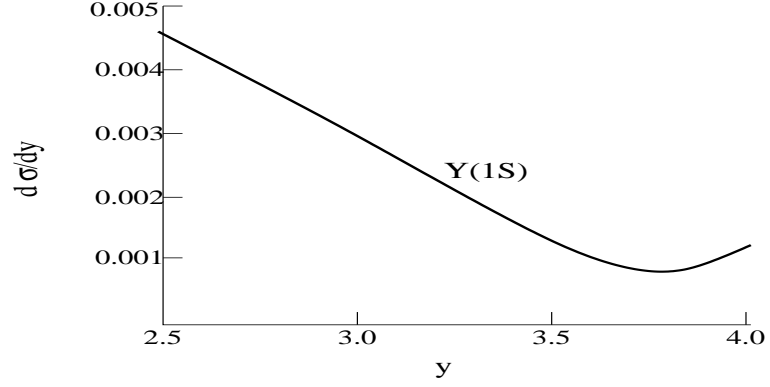


Figure 1: $d\sigma/dy$ for pp collisions at $\sqrt{s} = 2.76$ TeV producing $\Upsilon(1S)$.

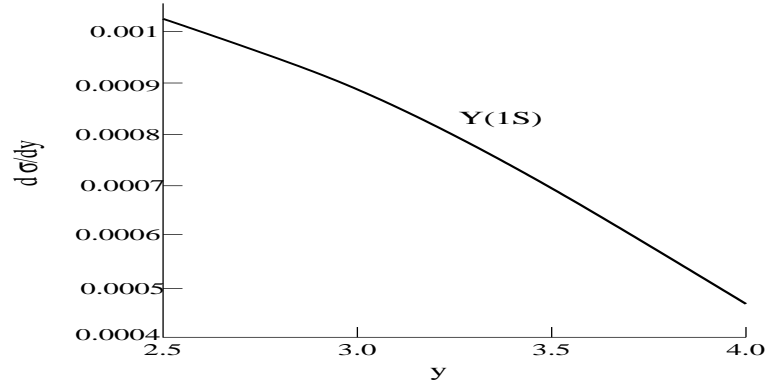


Figure 2: $d\sigma/dy$ for pp collisions at $\sqrt{s} = 7$ TeV producing $\Upsilon(1S)$.

Although the units in Figs. 1, 2 are in nb, the actual magnitude is uncertain due to the normalization of the state. The overall magnitude provides satisfactory estimates at forward rapidities for ALICE experiments.

2.1 Ratios of $\Upsilon(2S)$ and $\Upsilon(3S)$ to $\Upsilon(1S)$

The ratios of $\Upsilon(2S)$ and $\Upsilon(3S)$ for the standard model and for the mixed hybrid model [7], upon which the present work is based, are given by the fact that the $\Upsilon(3S)$ is 50% standard and 50% hybrid, as shown in Eq.(2). One finds (see Ref [8] for a detailed discussion) that

$$[\sigma(\Upsilon(2S))/\sigma(\Upsilon(1S))]_{mixed} = [\sigma(\Upsilon(2S))/\sigma(\Upsilon(1S))]_{standard} \simeq 0.27$$

$$[\sigma(\Upsilon(3S))/\sigma(\Upsilon(1S))]_{mixed} \simeq 2.5 \times [\sigma(\Upsilon(3S))/\sigma(\Upsilon(1S))]_{standard} \simeq 0.1 . \quad (5)$$

These are the same as those given in Ref [12], and are consistent with CMS measurements.

Note that recent measurements by Large Hadron Collider beauty(LHCb) experiment of the Υ production in pp collisions at $\sqrt{s} = 7$ TeV [13] in the rapidity range $2.0 < y < 4.5$ found the cross sections times the branching fractions to $\mu + \mu^-$: $\Upsilon(2S)/\Upsilon(1S) \simeq 0.25$, in agreement with the standard and mixed hybrid theories, while $\Upsilon(3S)/\Upsilon(1S) \simeq 0.12$, in agreement with the mixed hybrid theory, but in disagreement with the standard model.

3 Conclusions

We expect that our results for the rapidity dependence of $d\sigma/dy$ shown in Figs. 1 and 2 can be useful in the forward rapidity bottomonia measurements with ALICE detector at LHC. Also, the ratios of the production of $\Upsilon(3S)$ to $\Upsilon(1S)$ will be both a test of the validity of the mixed hybrid theory, and should also be a guide for ALICE. These experimental and theoretical studies will serve as a basis for tests of the creation of the QGP in ultra-relativistic heavy-ion collision experiments at the LHC.

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